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MODELING OF LDEF CONTAMINATION ENVIRONMENT

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SUMMARY

The Long Duration Exposure Facility (LDEF) satellite was unique in many ways. It was a large structure that was in space for an extended period of time and was stable in orientation relative to the velocity vector. There are obvious and well documented effects of contamination and space environment effects on the LDEF satellite. In order to examine the interaction of LDEF with its environment and the resulting effect on the satellite, the Integrated Spacecraft Environments Model (ISEM) was used to model the LDEF-induced neutral environment at several different times and altitudes during the mission.

INTRODUCTION

The LDEF satellite was placed in orbit to study the long-term effects of the space environment on materials and systems. It remained in orbit for almost 6 years, with its orbit decaying during the mission so that the environment experienced by the satellite changed with time. The LDEF satellite was a large structure which was stable in orientation relative to its velocity vector.

The large size, long duration of exposure, and orientation stability provided a unique opportunity for modeling the global neutral molecular environment induced by the satellite's motion in the ambient environment. Also, modeling of select local phenomena on the satellite was accomplished.

The intensity of outgassing was obviously maximum during the early part of the mission. This would be true also for the outgassing of the interior of the spacecraft which would be able to exit through vent holes around the experiments. The satellite face whose normal was into the velocity vector experienced the effect of the 5 eV atomic oxygen atoms. The opposite face experienced very little atomic oxygen exposure except for a small amount during retrieval and scattered atoms. More outgassing products could potentially be scattered back to the surface on the ram facing side of the vehicle.

Very noticeable brown deposits were present on the interior surfaces of the experiment trays. Modeling of a single vent was performed in order to compare the results with observed data.

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INTEGRATED SPACECRAFT ENVIRONMENTS MODEL (ISEM)

ISEM is a collisional molecular transport code which computes the molecular density and flux in a three-dimensional modeling volume for any number of user-defined molecular species. The LDEF geometry used for this modeling study is shown in Figure 1 and Figure 2.

MODELING PARAMETERS

Three different periods in the LDEF mission were modeled to obtain representative results over the mission lifetime. These periods were representative of the beginning, middle, and end of the mission timeline and corresponded to orbital altitudes of 463 km, 417 km, and 333 km, respectively. Table 1 shows the ambient values for the six different molecular species modeled at the beginning and ending periods. The values were obtained using the atmosphere predicting model MSIS86 and represent annual and orbital position averaged values for the periods modeled.

Table 1. Average ambient atmosphere density values (MSIS86).

Species $\#/cm^3$	Date 4/84	1/90
O	2.59×10^{7}	9.03×10^{8}
O_2	7.52×10^{3}	6.06×10^{6}
N	6.65×10^{5}	3.28×10^{7}
N_2	4.23×10^{5}	2.03×10^{8}
He	3.47×10^{6}	5.07×10^{6}
H	1.63×10^{5}	2.66×10^{4}

Table 2 shows the outgassing and erosion rates used for the modeling. External surfaces were modeled as having an average uniform outgassing rate which decreased with time. The initial outgassing rates were based on test data and the percentages of various materials present. Outgassing from internal surfaces was allowed to escape to the external environment via the numerous holes around the experiment trays. The external outgassing rate was assumed to decrease with an e folding time of 6,000 h. The internal outgassing rate was assumed to decrease with an e folding time of 7,000 h. The e folding times were based on Skylab measurements, taking into account differences in materials and materials control between the two programs. The average erosion rate was

Table 2. Outgassing and erosion rates.

Rate $g/cm^2/s$	463 km 4/84	333 km 1/90
External	2.0×10^{-9}	1.4×10^{-12}
Internal	2.0×10^{-10}	4.8×10^{-13}
Erosion	6.3×10^{-11}	2.2×10^{-9}

assumed to be 15 percent of Kapton for all the surfaces. The erosion rate given in Table 2 is for a surface normal to ram, a cosine dependence (relative to the velocity vector) was assumed for non-normal surfaces.

GENERAL MODELING RESULTS

ISEM was used to compute the density of every tracked species throughout the three-dimensional modeling volume for the mission beginning, middle, and end cases described previously. Figures 3 and 4 show the iso-density contours for a plane of values from the three-dimensional modeling volume. The total density value is the sum of ambient species, surface reemitted ambient species, internal and external outgassed species, and the scatter portions of all species. The contour values have been normalized to the total undisturbed ambient density at the respective altitude. Figure 3 shows the total iso-density contours for the early mission case at an altitude of 463 km. A slight ram buildup can be seen in front of the vehicle (velocity vector from left to right), but the density around the vehicle is dominated by the outgassing. Figure 4 shows the total iso-density contours for the late mission case at an altitude of 333 km. There is a strong density buildup in front of the vehicle due to ambient and erosion products. The wake is very well defined, and although the densities are much less than on the ram side, the density in the wake region is still dominated by the outgassed species.

From the standpoint of surface materials interaction with the molecular environment, molecular flux of the different species is much more important than density. Flux of each tracked species was computed to each of the LDEF facets. Figures 5 through 8 show the surface incident flux at the highest and lowest modeled altitudes for atomic oxygen and molecular nitrogen. In the figures, the surface incident flux is plotted as a function of incident angle as measured from the ram direction. The term "direct" on figures refer to flux of molecules which have not had a collision. They still retain the kinetic energy of the orbital velocity (in the spacecraft reference frame). Figures 9 and 10 show the flux of outgassed and erosion products at the highest and lowest modeled altitudes, respectively. Note that there is no direct flux in these figures because only transport via scattering can produce the return flux of these species to the external surface. This may not be true on the scale of individual experiment trays. These figures illustrate, as expected, that the ram surfaces are dominated by the direct flux and that the wake surfaces are dominated by scattered flux. The calculations do show that a scatter flux exists even at nearly 180°. Also, the return flux in the wake regions is always dominated by outgassing products, even late in the mission when outgassing is lowest.

SMALL SCALE MODELING RESULTS

A modeling effort was undertaken to examine the molecular flux through a small aperture and the resulting incident flux on an internal surface, namely, the side of an experiment tray. Figure 11 shows the geometrical relationship of the aperture and the internal surface. Incident atomic oxygen was modeled as entering the aperture and then allowed to expand due to its thermal distribution. The atomic oxygen pattern incident on the side of the experiment tray was consistent with the deposition pattern observed on the side of the tray. Also, rivets and bolt heads shadowed portions of the experiment tray from atomic oxygen impingement and no deposition was observed. The modeling results are consistent with the view that outgassing products from inside the LDEF were adsorbed onto surfaces. Where atomic oxygen was able to flow through vents and apertures and impinge on these surfaces, resulting chemical interaction caused a permanent deposit to form.

CONCLUSIONS

Both large-scale and small-scale modeling of LDEF and its environment was accomplished for specific missions times, early and late in the mission. The modeling results were consistent with observations on LDEF and do provide some insight into important processes ongoing in determining the overall environment and contamination potential. Early in the mission, the environment was dominated by outgassing of the LDEF itself. Outgassing dominated the wake region density for the entire mission. For later times in the mission, the ram side density was many times that of the ambient. This was caused by a combination of accommodation and emission of oxygen, emission of reaction products and scattered molecules. The flux to the surface is dominated by direct atomic oxygen impingement, but a significant flux of scattered molecules exists. Even on the wake side, the scattered flux can be observed at angles up to 180°. The return flux of erosion species near the end of the mission was an order of magnitude greater than the return flux of outgassed products early in the mission.

Internal deposition has been observed on LDEF around vents and near apertures where atomic oxygen could flow unobstructed to the interior. Modeling of this flow indicated that the observed patterns were consistent with the thermally distributed flux of ambient atomic oxygen. The atomic oxygen must be reacting with internally outgassed contaminants on the internal surfaces to leave the observed deposits.

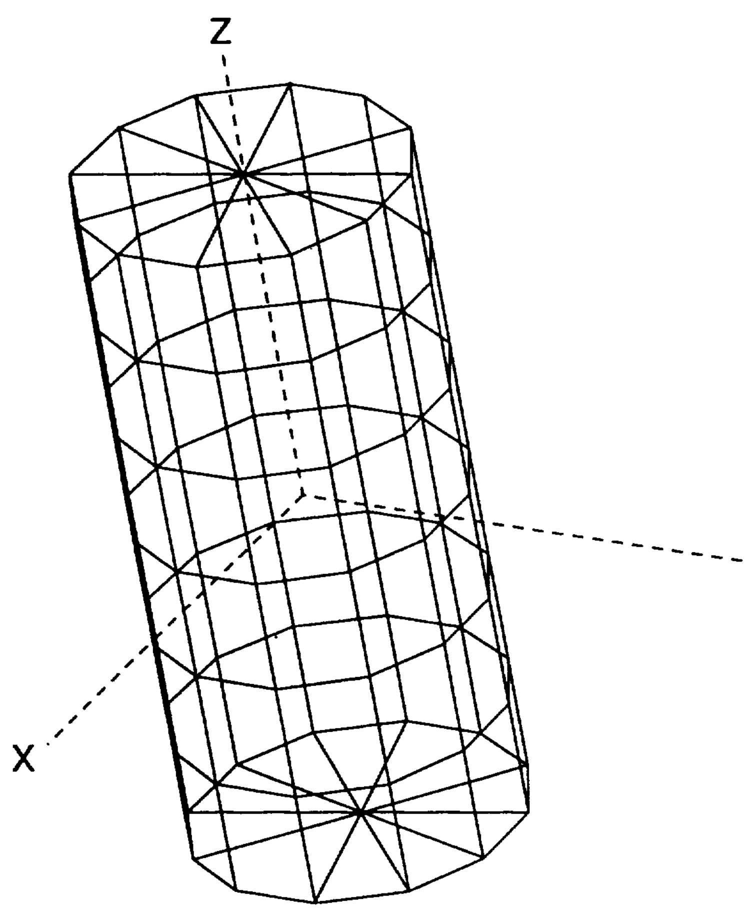

Figure 1. Geometry of LDEF model.

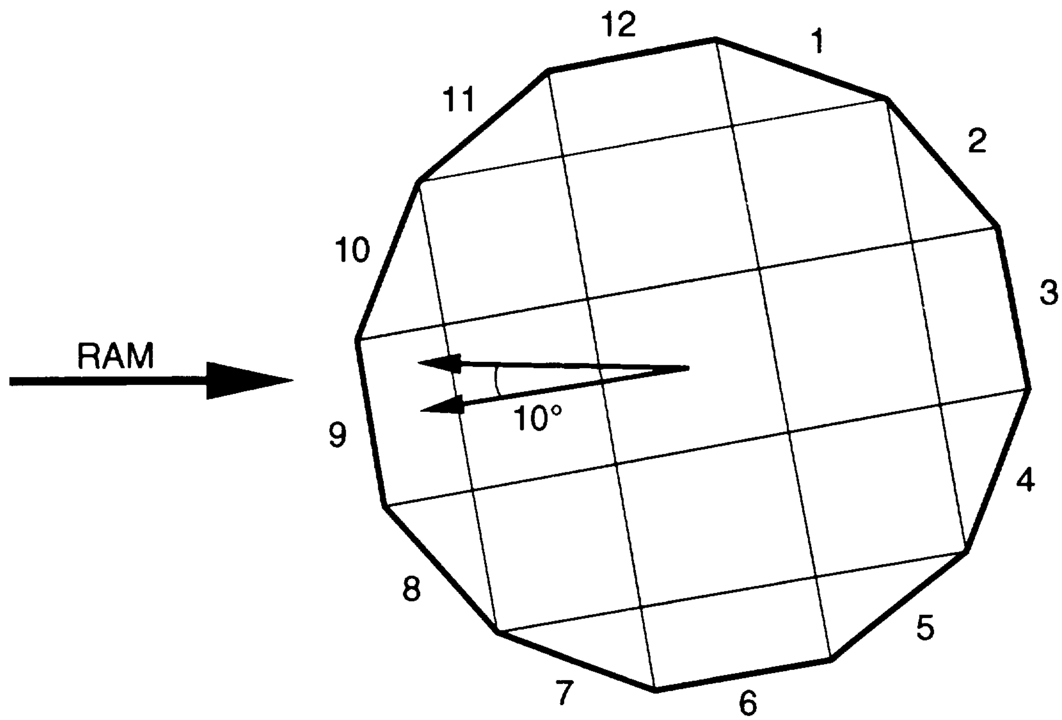

Figure 2. Ram direction orientation used in model.

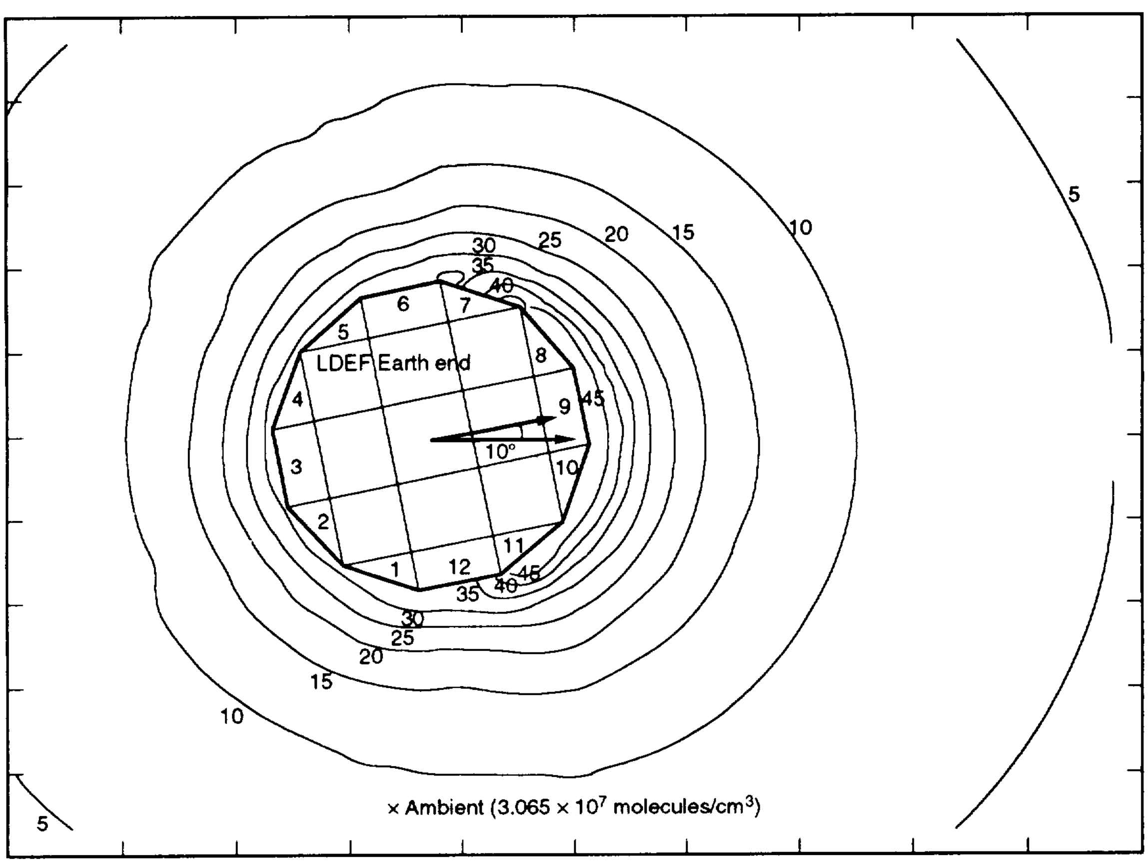

Figure 3. Total density at 463 km.

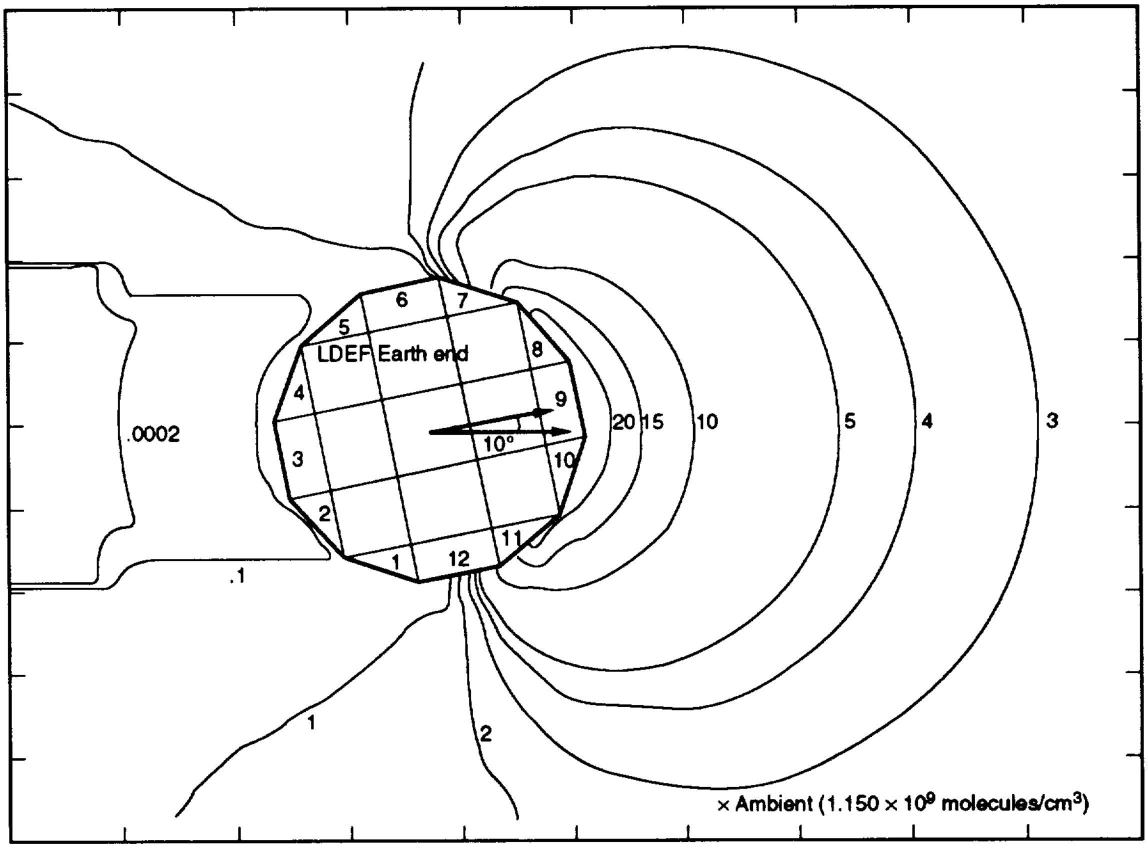

Figure 4. Total density at 333 km.

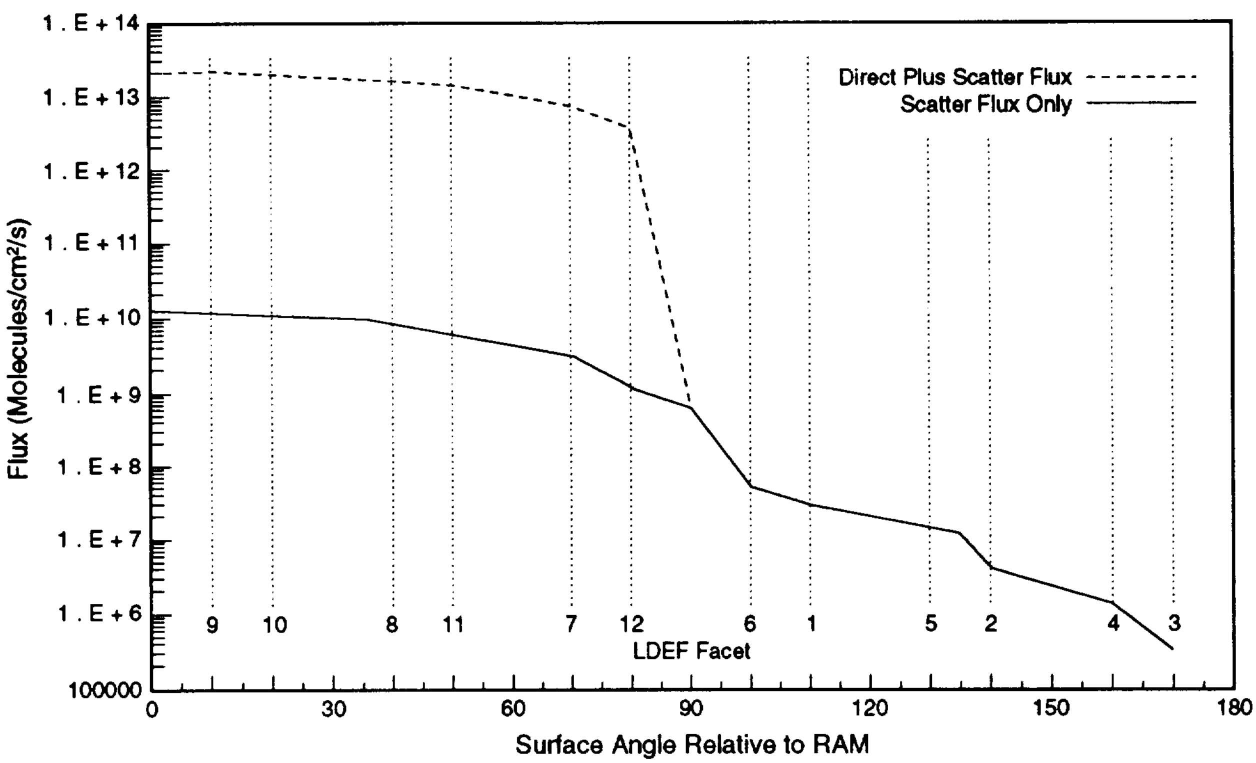

Figure 5. Atomic oxygen flux on LDEF surfaces at 463 km.

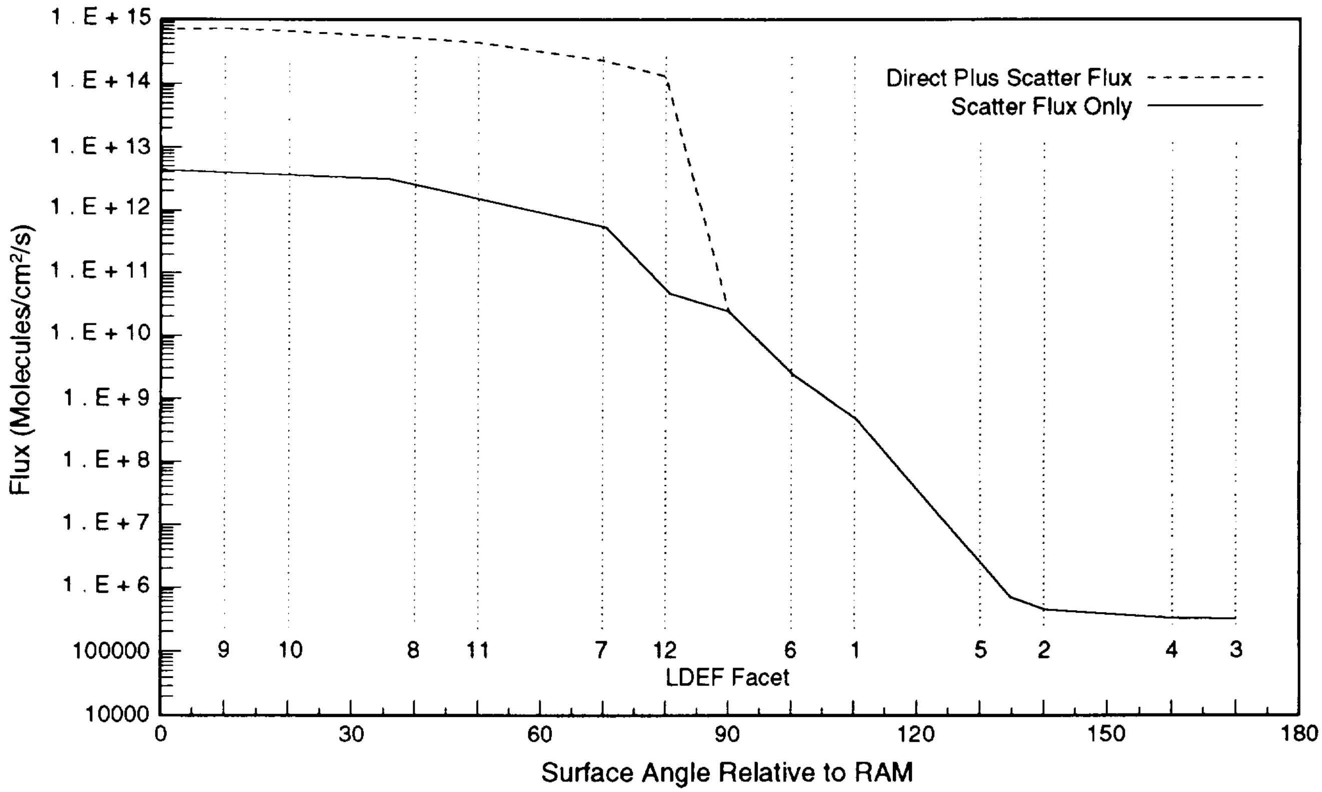

Figure 6. Atomic oxygen flux on LDEF surfaces at 333 km.

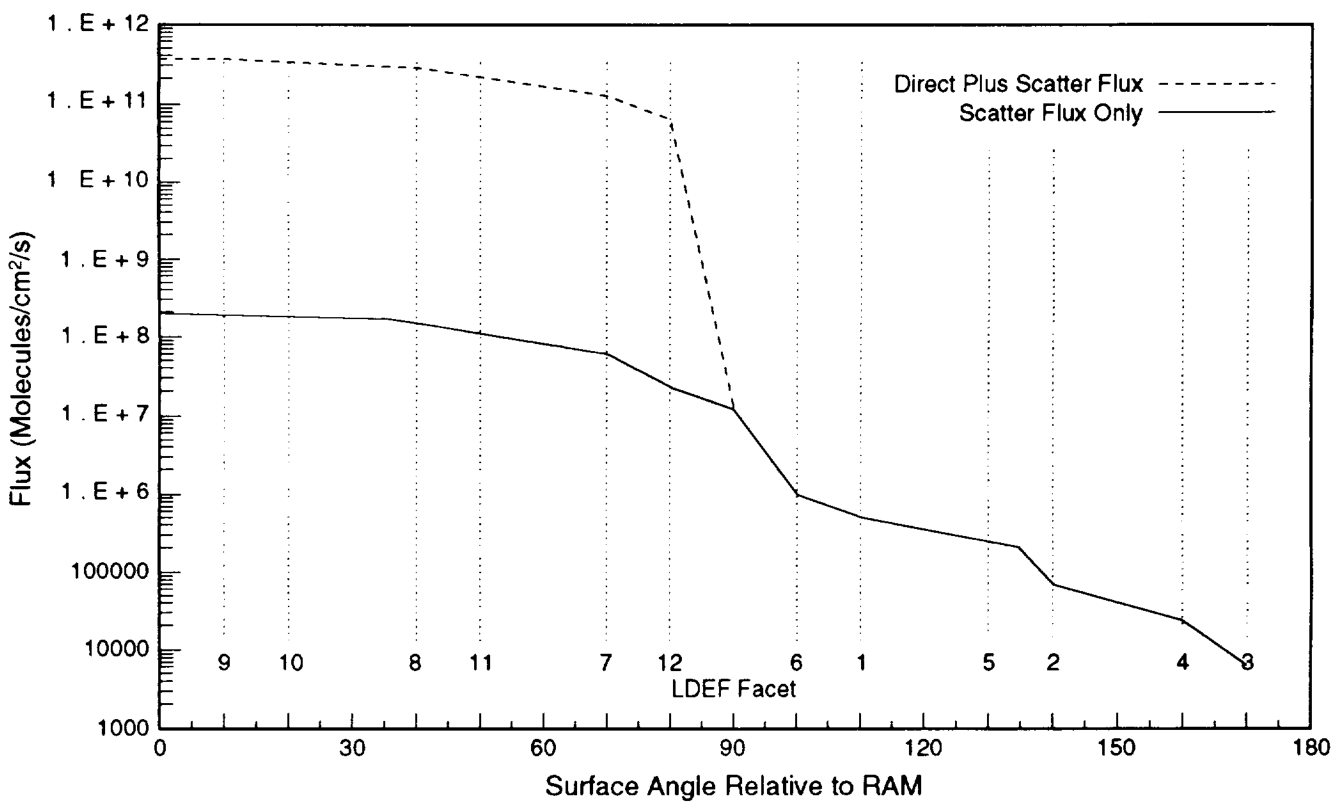

Figure 7. Molecular nitrogen flux at 463 km.

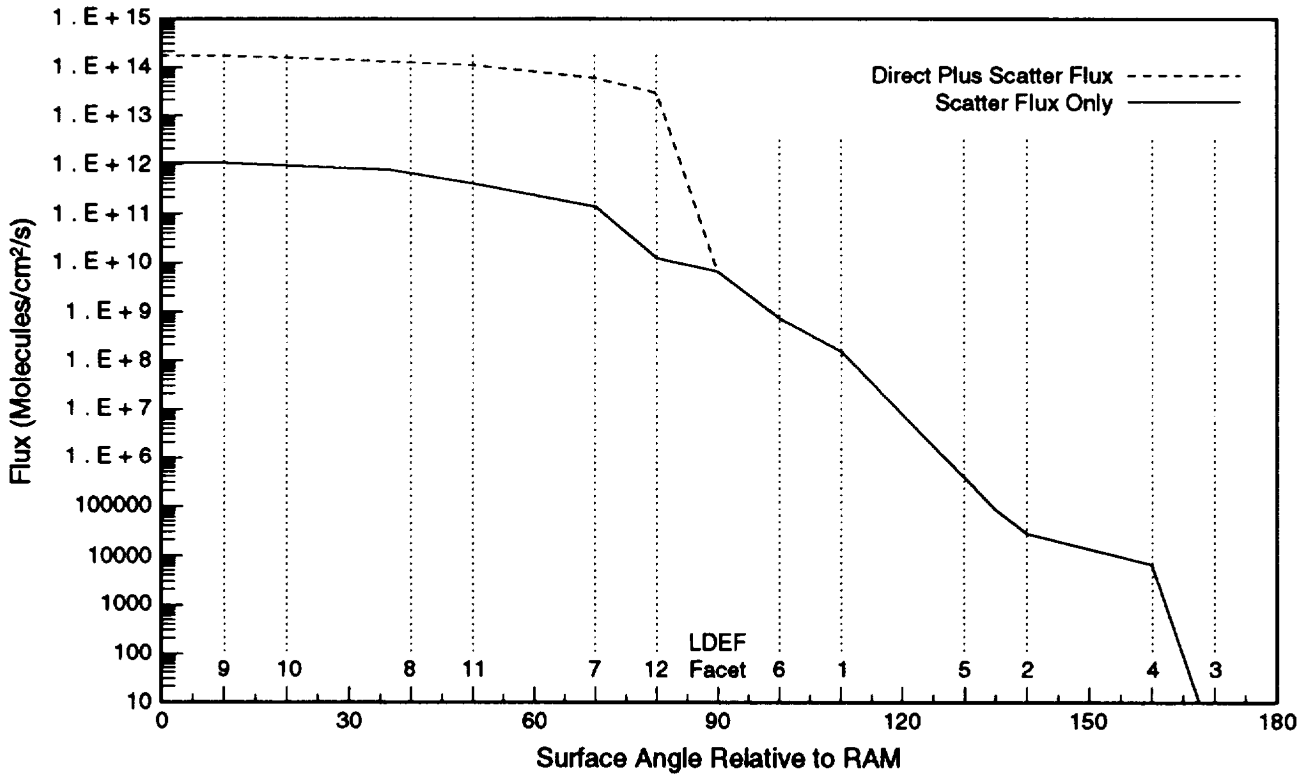

Figure 8. Molecular nitrogen flux at 333 km.

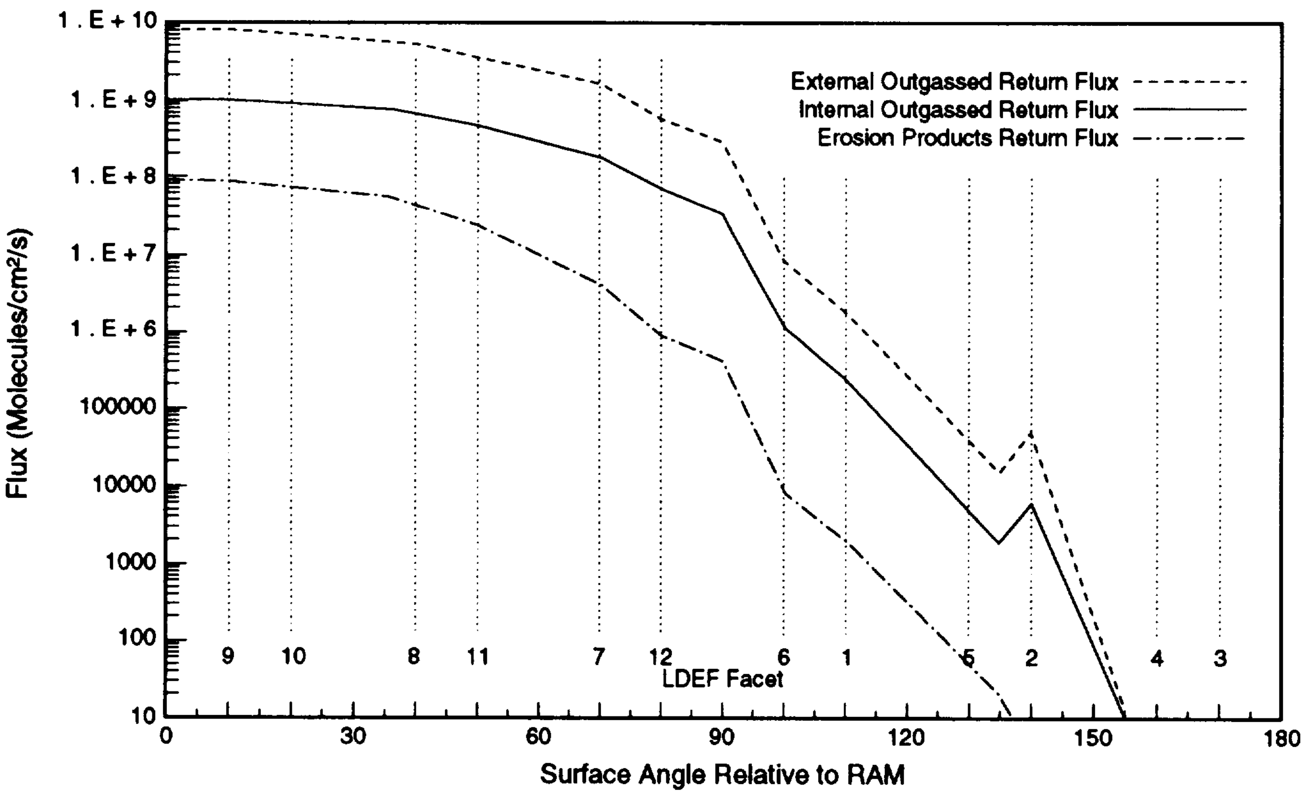

Figure 9. Outgas and erosion product flux at 463 km.

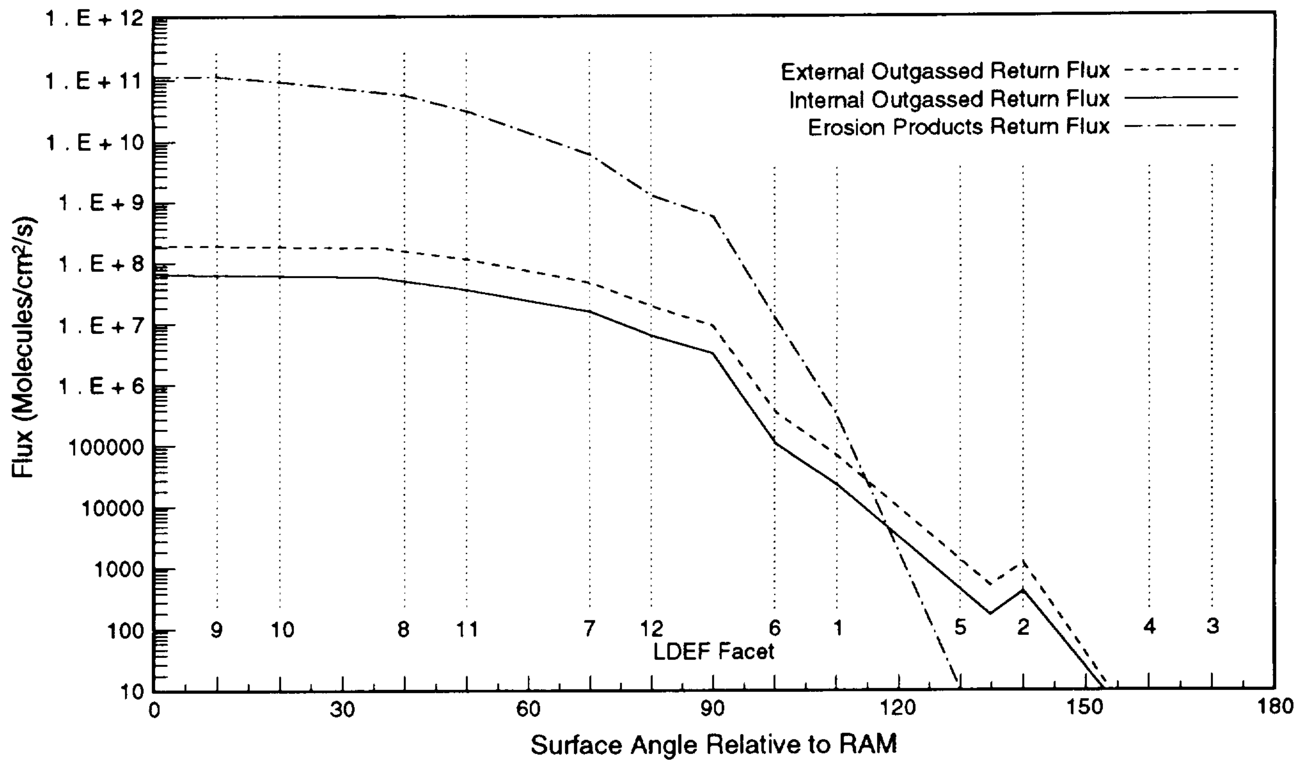

Figure 10. Outgas and erosion product flux at 333 km.

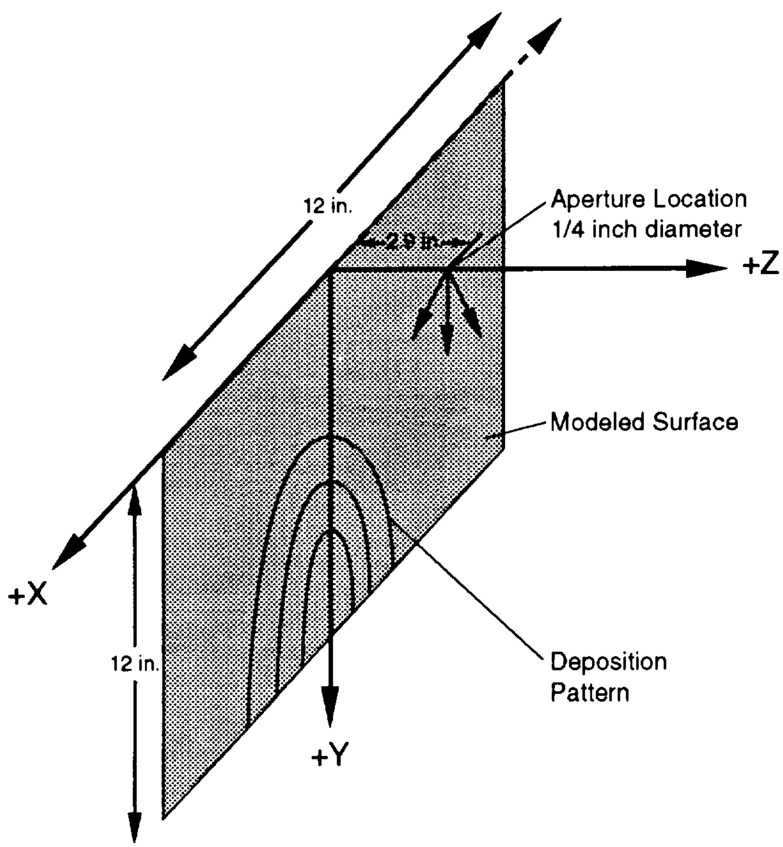

Figure 11. Geometry of atomic oxygen flux to interior.